AD-A249 225

ARO 24610.1-GS-UIF

Final Report

ARO Geoscience Center Fellowships

2

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Research Triangle Park, NC 27709

ARO Grant DAAL03-86-G-0190

Period Covered: September 1, 1986 - November 30, 1991

January 1992

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE 1/27/92

3. REPORT TYPE AND DATES COVERED Final (9/1/86 - 11/30/91)

4. TITLE AND SUBTITLE

ARO Geoscience Center Fellowships

5. FUNDING NUMBERS

DAAL03-86-G-0190

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Cooperative Institute for Research in the Atmosphere (CIRA)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
ATTN: SLCRO-URI-86
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 24610.1-GS-UIF

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

~~Distribution and availability per DODD 5230.24, "Distribution Statements on Technical Documents."~~

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The fellowship grant was supported by the ARO Center for Geosciences located at the Foothills Campus at Colorado State University under the auspices of the Cooperative Institute for Research in the Atmosphere (CIRA). The Center for Geosciences at Colorado State University was established in collaboration with the Army Research Office on October 1, 1986.

The Center brought together a wide range of expertise into one focused multi-disciplinary research framework. Under the administrative structure of CIRA, the Center involved investigators from the University's Departments of Atmospheric Science, Civil Engineering, Electrical Engineering, Earth Resources, Forest and Wood Science, Physics and Psychology.

The technical components of the Center are in Atmospheric and Surface Remote and In-Situ Sensing; Atmospheric Modeling; Hydrologic Modeling; and Geoscience Information Extraction.

14. SUBJECT TERMS

Fellowship Grant

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

ABSTRACT

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1. INTRODUCTION

The Geosciences Graduate Fellowship program was established by the Army Center for Geosciences at Colorado State University in September, 1986. This five year program was funded by the Army Research Office (ARO) in conjunction with the Center for Geosciences research program. The Geosciences Fellowship program served to increase the science base of the Army and the Nation by educating students in technical disciplines while fostering an appreciation of the Army's research objectives, methods, and facilities. The coordination between the Fellowship and research activities provided the Fellows with an environment of excellence in basic, interdisciplinary research. In return, the Fellows contributed their talents to help the Center meet its research goals.

The Geosciences Fellows were selected on the basis of their qualifications demonstrated by prior academic gradepoint, Graduate Record Examination scores, written recommendations, and their interest in research topics being performed at the Center. The Fellows were enrolled in academic programs while pursuing their research, leading to Master of Science or Doctor of Philosophy degrees. These degrees were obtained in:

- Atmospheric Science,
- Civil Engineering,
- Electrical Engineering,
- Physics,
- Computer Science,
- Earth Resources, or
- Psychology.

A total of 18 graduate degrees have been granted to date as a direct result of the Fellowship program. Another eight students still are working to fulfill their degree requirements following the end of the program in November, 1991. Seven of the degrees granted were Ph.D.'s and 11 were M.S.'s. A list of Fellows and summary of degrees obtained is shown in Table 1. We note that several graduate students were supported by the Center for Geosciences research program as Graduate Research Assistants. The work of those students is not summarized here, but will be included in the Geosciences Research Final Report. The Geosciences Fellowship program was administered under the hierarchy shown in Figure 1, whereas the individual Fellows were supervised by their academic departments acting through a faculty advisor.

This report contains a list of the thesis and dissertation titles completed by the Geosciences Fellows, shown in Table 2. It also includes the abstracts of those treatises.

Table 1

Degree Information for ARO Geosciences Fellows

Fellow Name	Degree	Academic Department	Advisor
Raul Alvarez	Ph.D.	Physics	Dr. J. She
Deborah Anthony	M.S.	Earth Resources	Dr. S. Schumm
Bonnie Ashburn	M.S.+	Atmospheric Science	Dr. E. Reiter
Charlotte Atwater	M.S.	Atmospheric Science	Dr. T. Vonder Haar
James Bossert	Ph.D.	Atmospheric Science	Drs. W. Cotton/R. Pielke
Thomas Burke	M.S.*	Civil Engineering	Dr. P. Julien
Loren Caldwell	Ph.D.*	Physics	Dr. C. She
Thaddeus Cline	M.S.	Civil Engineering	Drs. D. Simons/P. Julien
Jeff Copeland	Ph.D.*	Atmospheric Science	Drs. W. Cotton/R. Pielke
Keely Costigan	Ph.D.*	Atmospheric Science	Dr. W. Cotton
Jeff Fredericks	Ph.D.+	Civil Engineering	Dr. D. Simons/P. Julien
Scot Greenidge	M.S.+	Electrical Engineering	Dr. T. Brubaker
Benjamin Hayes	Ph.D.*	Earth Resources	Dr. S. Schumm
Russell Huonder	M.S.	Computer Science	Dr. T. Brubaker
Andrew Jones	M.S. Ph.D.*	Atmospheric Science	Dr. T. Vonder Haar
Scot Makinen	Ph.D.+	Electrical Engineering	Dr. T. Brubaker
Robert McCoy	M.S.	Physics	Dr. G. Stephens
Michael Meyers	M.S. Ph.D.*	Atmospheric Science	Dr. W. Cotton
Glenn Moglen	M.S.	Civil Engineering	Drs. D. Simons/P. Julien
Fred Ogden	Ph.D.	Civil Engineering	Dr. P. Julien

* In progress
\+ Left program without degree

Table 1 (cont'd)

Fellow Name	Degree	Academic Department	Advisor
Peter Olsson	M.S.	Atmospheric Science	Dr. S. Cox
Jerry Richardson	Ph.D.	Civil Engineering	Dr. P. Julien
William Smith	M.S.	Atmospheric Science	Dr. S. Cox
Otto Stein	Ph.D.	Civil Engineering	Dr. P. Julien
Joseph Turk	Ph.D.	Electrical Engineering	Dr. V. Bringi
Paul Weiler	M.S.	Psychology	Dr. R. Loomis
Douglas Wesley	Ph.D.	Atmospheric Science	Dr. R. Pielke
Paul Wolyn	Ph.D.*	Atmospheric Science	Dr. T. McKee

* In progress
\+ Left program without degree

Table 2

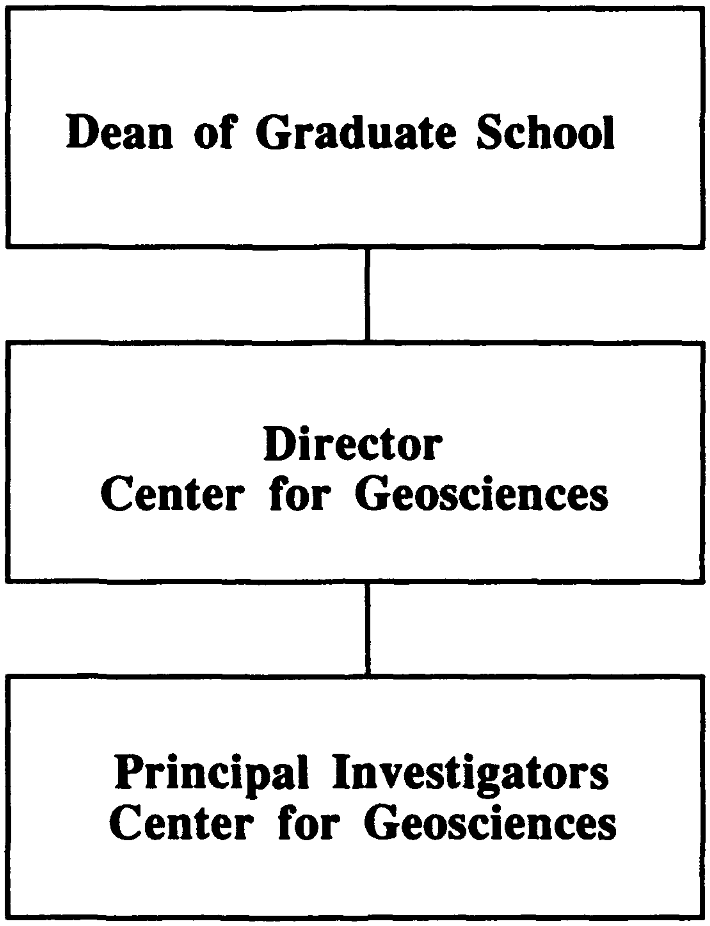
Geosciences Fellows Thesis and Dissertation Titles

Name	Title	Degree
Raul John Alvarez, II	Measurement of Tropospheric Temperature and Aerosol Extinction Using High Spectral Resolution Lidar	Ph.D.
Deborah J. Anthony	Stage Dependent Channel Adjustments in a Meandering River, Fall River, Colorado	M.S.
Charlotte A. Atwater	Rader-Derived Estimates of Latent Heating Rates in a Convective Storm	M.S.
James E. Bossert	Regional-Scale Flows in Complex Terrain: An Observational and Numerical Investigation	Ph.D.
Thaddeus Cline	Development of a Watershed Information System for HEC-1 with Application to Macks Creek, Idaho	M.S.
Benjamin Hayes	Climatic and Geomorphic Controls on the Suspended Sediment and Salt Loads in the Upper Colorado River Basin	Ph.D.
Russell J. Huonder	Visualization of Three-Dimensional Scientific Data Using Octrees	M.S.
Andrew S. Jones	Microwave Remote Sensing of Cloud Liquid Water and Surface Emittance Over Land Regions	M.S.
Robert F. McCoy, Jr.	Frequency Chirp of a Hybrid Doppler Lidar	M.S.
Michael P. Meyers	An Evaluation of the Factors Affecting Wintertime Quantitative Precipitation Forecasts in an Explicit Cloud Model over Mountainous Terrain	M.S.
Glenn E. Moglen	The Effects of Spatial Variability of Overland Flow Parameters on Runoff Hydrographs	M.S.
Fred L. Ogden	Two-Dimensional Runoff Modeling with Weather Radar Data	Ph.D.
Peter Olsson	Inference of Horizontal Temperature Gradients using Passive Radiometric Methods	M.S.
Jerry R. Richardson	The Effect of Moving Rainstorms on Overland Flow Using One-Dimensional Finite Elements	Ph.D.

Table 2 (cont'd)

Name	Title	Degree
William L. Smith, Jr.	The Broadband Radiative Properties of Cirrus Clouds Deduced from Aircraft Measurements During FIRE	M.S.
Otto R. Stein	Mechanics of Headcut Migration in Rills	Ph.D.
Joseph Turk	Microwave Remote Sensing of a Precipitating Atmosphere	Ph.D.
Paul A. Weiler	Social Loafing and Vigilance Decrement While Monitoring Different Levels of Simulated Air Traffic	Ph.D.
Douglas A. Wesley	The Influence of Topography on Colorado Front Range Snowstorms	Ph.D.

Figure 1. Administration of Geosciences Fellowship Program



2. ABSTRACTS OF THESES AND DISSERTATIONS

ABSTRACT

MEASUREMENT OF TROPOSPHERIC TEMPERATURE AND AEROSOL EXTINCTION HIGH SPECTRAL RESOLUTION LIDAR

Raul John Alvarez, II
Physics Department

A high spectral resolution Rayleigh-Mie lidar system capable of measuring relative temperature and aerosol profiles in the troposphere has been developed. The use of a narrowband laser transmitter along with an atomic vapor cell as a variable width bandstop filter allows for the separation of molecular and aerosol scattering signals. Using two of these filters with different widths and a newly developed lidar inversion method it is possible to determine relative temperature, pressure, and density profiles of the troposphere. This separation also makes a quantitative measurement of aerosol extinction coefficient profiles possible.

In principle, the information required in addition to the lidar signals for determining atmospheric and aerosol properties with this Rayleigh-Mie lidar is: the theoretical Rayleigh-Brillouin spectrum for scattering of narrow bandwidth laser light, independent measurements of the filter transmission functions, the assumption that the atmosphere acts as an ideal gas in hydrostatic equilibrium, and an approximate atmospheric pressure at one reference altitude. Profiles of the tropospheric state variables of temperature, pressure, and density are determined from signals averaged over 20 minutes. Once profiles of the atmospheric variables are determined, the aerosol extinction coefficient profiles are calculated.

A systematic offset in the lidar temperature profiles is seen however in practice when compared to balloon sonde measurements. Further laboratory experiments have established that the systematic offset is real and is consistent between laboratory and field measurements. This repeatable offset can be eliminated by normalizing the temperature at a reference altitude to an independently measured or estimated value.

The development and implementation of this high spectral resolution lidar and the first simultaneous measurements of tropospheric temperature and aerosol profiles from 0.2 km to 8 km are presented. The precision at 1 km altitude is ±10 K for temperature measurement, ±3% for backscatter ratio, and ±5% for aerosol extinction coefficient. At 5 km, these values are ±12 K for temperature, ±4% for backscatter ratio, and ±100% for extinction coefficient. Suggestions to determine the cause of the offset and to reduce the relative uncertainties are also discussed.

ABSTRACT

STAGE DEPENDENT CHANNEL ADJUSTMENTS IN A MEANDERING RIVER, FALL RIVER, COLORADO

Deborah J. Anthony
Earth Resources Department

Dam failure increased bedload supply to Fall River, a very sinuous, low gradient, snowmelt-fed stream, by a factor of 1000. This sediment is mobile at nearly all discharges, and thus channel topography is able to change with stage. In a two-bend study reach, the relationships between flow and mobile bed material were studied by measuring bedload transport rates, bed and water surface topography, and downstream and cross-stream velocity patterns on 22 cross sections. Measurements were made at different discharge levels through the 1986 runoff season.

At bankfull discharge, bend cross sections showed maximum asymmetry, with point bar platforms built up to the water surface and thalwegs excavated to their greatest depth. Cross-stream flows included zones of high turbulence, containing bed and bank cells in the thalweg region, with helical flow occurring over the point bar slope and outward flow only occurring over the point bar platforms. Bedload transport was greatest over the point bar slope, and almost zero through the thalweg. Sorting was continuous through each bend.

At intermediate flows, cross section symmetry increased due to lateral erosion of the point bar platform. Helical flows occupied a larger portion of individual cross sections, including the thalweg. In planform, however, the zone of helical flow had split into two smaller cells in each bend. Bedload transport had shifted outward from its high flow position, due to point bar progradation towards the cutbank, so that some sediment movement was recorded in the thalweg.

At low flows, characteristic of fall and winter, cross section symmetry was at a maximum. Additional erosion of the high point bars had occurred, but the greatest change was due to thalweg filling. Cross-stream flows were weak and chaotic for the most part, and bedload transport was more uniform across the channel than at higher discharges. Sorting was discontinuous, and it was confined to small pools in the otherwise flat channel.

In this mobile bed channel, bed topography is a function of cross-stream flow and bedload transport patterns, which are controlled by stage.

ABSTRACT

RADAR-DERIVED ESTIMATES OF LATENT HEATING RATES IN A CONVECTIVE STORM

Charlotte A. Atwater
Atmospheric Science Department

The importance of latent energy in storm dynamics and the global energy balance has long been recognized by atmospheric researchers. This study focuses on the latent heating and cooling in an isolated, microburst-producing thunderstorm in Alabama on the 20th of July, 1986. Data used in this work were recorded by NCAR CP-2 radar. 10 cm horizontal and vertical reflectivity signals (Z_H and Z_V, respectively) are used to calculate the difference reflectivity, $Z_{DP} = 10\log(Z_H - Z_V)$, which is then used to calculate the fraction of the horizontal reflectivity signal arising from ice hydrometeors. This information is then used to quantify liquid and ice water contents and the rainfall rate. The time rate of change of these three quantities are then used to derive latent heating rates.

The fraction of the reflectivity signal arising from ice hydrometeors is based on the degree of decorrelation between the Z_{DP} and Z_H signals in mixed-phase regions. Liquid water contents are calculated using a combination of 1) an empirical relation relating liquid water content to radar reflectivity for mixed-phase regions and 2) calculating liquid water contents from radar-derived parameters of the raindrop size distribution for pure liquid water regions. Ice water contents are calculated from an empirical relation relating liquid water content to radar reflectivity with corrections made to account for differences between the indices of refraction and typical densities of liquid and ice hydrometeors. Finally, rainfall rates are calculated using an empirical relation relating rainfall rate to coincident differential reflectivity, Z_{DR}, and Z signals. Estimated error levels, including instrument error, are approximately ±10% for the time rate of change of liquid water content, ±70% for the time rate of change of ice water content, and ±40% for rainfall rate.

Calculated vertical ice fraction profiles indicate that the storm consisted almost entirely of liquid water during its early stages. Glaciation began at the top of the storm and continued to progress downward through the storm with the descent of the core of maximum reflectivity signal. The ice fraction profile increased slightly from nearly 0.0 to about 0.1 at the surface at the time the microburst was observed to impact the ground. This increase is most likely a result of pea-sized hail reaching the surface. These conclusions confirm those drawn in other studies of the 20 July 1986 case.

The latent heating results indicate that heating and cooling caused by condensation and evaporation, respectively, account for roughly 90% of the total heating and cooling in this storm, with the remaining 10% coming from melting and freezing processes. Net latent heating rates (total heating rate minus total cooling rate) increased nearly steadily from the early stages of the storm until about 10 minutes before the microburst occurred, at which point it began to decrease. The net latent heating rate went from positive to negative less than 5 minutes before the microburst impacted the ground. Towards the end of the decaying stage of the storm, net latent heating was approaching zero.

ABSTRACT

REGIONAL-SCALE FLOWS IN COMPLEX TERRAIN: AN OBSERVATIONAL AND NUMERICAL INVESTIGATION

James E. Bossert
Atmospheric Science Department

An observational program has been conducted to obtain information concerning thermally-driven flows in complex terrain on meso-β to meso-α scales (100 - 500 km). Data were collected from remote surface observing systems at exposed mountaintop locations throughout the state of Colorado, over the summers of 1984-1988. These field experiments have been called the Rocky Mountain Peaks Experiments (ROMPEX). The observations from ROMPEX have been supplemented with data from other remote surface networks, special soundings, upper-air observations, and radar and lightning strike information to provide an adequate description of the flows and weather of interest.

The observations have shown the development of a recurrent "regional-scale" circulation system across the Colorado mountain barrier, operating on a diurnal time scale. The basic structure of the flow system consists of a daytime inflow phase toward the mountains along the Continental Divide, and a nocturnal outflow away from this high terrain. Long-term averages show this circulation system to be the dominant wind pattern at several high altitude stations, revealing its climatological significance. Attention has been focused upon the nocturnal phase of the circulation system along the western slope of the mountain barrier. Here, the winds are particularly strong and from a southeasterly direction, which is generally counter to the upper-level winds, and onset abruptly in early evening with steady flow thereafter. Soundings have shown this nocturnal current to be shallow and within a distinct stable air mass. Convective storms are found to enhance this southeasterly flow regime.

Numerical simulations have been performed with the Colorado State University Regional Atmospheric Modelling System (CSU-RAMS) to provide further insight into the physical mechanisms forcing the observed regional-scale circulation system. The model simulations include both idealized two- and three-dimensional experiments, as well as a three-dimensional case study experiment using actual data for the initialization. The three-dimensional simulations use two-way interactive grid nesting and a realistic representation of topography over the region of interest.

The idealized three-dimensional experiment showed that thermal forcing over realistic topography in conditions of negligible, or weak ambient flow, is capable of producing many of the flow features observed throughout the diurnal cycle. This experiment further showed how the deep mountain-plains solenoid along and above the Front Range crest evolves in late afternoon into a shallower density current, which then propagates westward over the mountains of the western slope. This unexpected flow phenomenon is the primary process responsible for the strong nocturnal southeasterly winds found in observations. Sensitivity experiments show that the particular terrain configuration through an east-west cross-section of the Colorado mountains is important to the generation of this unusual circulation. The strong thermal gradient produced by differential heating of the topography is the primary driving force in the density current evolution. Coriolis influence maintains the steady nocturnal south-southeast winds over the western slope. Additional experiments show that the diurnally evolving regional-scale circulation system over the

Colorado Rocky Mountains is a robust feature which can occur over a range of ambient flow and stratification conditions. Soil moisture experiments reveal that wet soil along the eastern slope and dry along the western slope aids the development of the westward propagating density current.

The diurnal evolution of the circulation system on the case study day was in fair agreement with many of the observed circulation features. This experiment also revealed that synoptic-scale forcing can influence the development of the regional-scale circulations in preferential regions along the eastern slope of the mountain barrier. As a result of the numerical experiments four phases of the thermally forced regional-scale diurnal circulation system have been identified. These consist of a daytime mountain boundary layer development phase, a late afternoon transitional phase, an evening propagating density current phase, and a late night adjustment phase.

ABSTRACT

DEVELOPMENT OF A WATERSHED INFORMATION SYSTEM FOR HEC-1 WITH APPLICATION TO MACKS CREEK, IDAHO

Thaddeus Cline
Civil Engineering Department

A micro computer based Watershed Information System (W.I.S.) is developed to assist in the preparation of HEC-1 input files. This system consists of three phases. Phase I utilizes the capabilities of AutoCAD version 9 and three AutoLISP programs: BASINS, PLANES and CHANNELS, to extract, organize and display watershed data. Phase II uses a FORTRAN program: CN, to calculate some HEC-1 parameter values. Phase III utilizes a PASCAL program: HECUPDATE, to create HEC-1 input files. Input into the system includes topographic, soils, land use, watershed geometry data, and a skeletal HEC-1 input file. Output from the system consists of a summary User Reference File, a Soils File, a Land Use File, a watershed Geometry File, a Curve Number File and HEC-1 input file which is ready to run. This thesis presents the W.I.S.: describing its use, applying it and providing program listings.

The W.I.S. is applied in a HEC-1 modeling study of Macks Creek Watershed: a small, arid mountainous watershed located in southwest Idaho. First the W.I.S. generates a database and HEC-1 input files. Then these files are used to calibrate the model to a rainfall-runoff event on June 5 and 6, 1967. The input files from the calibrated model are then used to simulate the response of the watershed to a heavy rainfall event on August 23, 1965. The W.I.S. developed and applied in this thesis greatly facilitates watershed data extraction and organization, data display, HEC-1 parameter calculation and the creation of HEC-1 input files. Two FORTRAN programs HECQ.FOR and HEC123.FOR reformat HEC-1 output into files which can be imported by a spreadsheet program for graphical representation of simulation results. HECQ.FOR also compares the simulated and the measured hydrographs by calculating absolute and relative error, the mean and standard deviation of these errors and the volume of the difference between the simulated and the measured hydrographs.

It is shown that using abnormally low values for roughness coefficients in HEC-1 had the same effect on the simulated hydrograph as the introduction of collector channels. It is also shown that using the base flow correction option of HEC-1 modifies output hydrographs in a way that can erroneously indicate that volume of direct runoff is not preserved when varying routing parameters. This is due to a "masking" effect justifying caution in hydrograph analysis using this option. Finally, a sensitivity analysis of some HEC-1 parameters is performed. Results of this analysis are useful for developing and operating the W.I.S. and for model calibration. The sensitivity analysis shows that HEC-1 is very sensitive to values of curve number and initial abstraction, moderately sensitive to values of overland flow roughness coefficient and overland flow length, and slightly sensitive to open channel flow roughness coefficient and computational time interval.

ABSTRACT

VISUALIZATION OF THREE-DIMENSIONAL SCIENTIFIC DATA USING OCTREES

Russell J. Huonder
Computer Sciences Department

Meteorological sensors with three-dimensional digital output have created an interest in graphical rendering of atmospheric conditions for scientific visualization. The goal of visualization is improved understanding of atmospheric phenomena. The renderings should be fast, and should accurately represent the data. A traditional approach to three-dimensional object rendering is to display the data using a geometric modeling system, but because these systems model object surfaces, volumetric data sets can not be effectively represented. The smooth surfaces these systems produce are also undesirable since data integrity can be lost.

In this thesis, the *octree* structure is presented as a data structure which efficiently and effectively represents the observational data. An introduction to this structure is presented along with advantages and disadvantages. Observational data sets used are discussed along with a description of how the data is encoded. Various existing algorithms for displaying the structure are reviewed, and then a new algorithm for visualization of the octree using arbitrary rotations is presented. Within this discussion various illumination models are considered, as well as other parameters which permit a focused view of the data such as slicing and thresholding. A technique for fusing data sets is then presented with recommendations for future work in this area.

The algorithms developed for manipulation of the octree allow three-dimensional visualization of scientific data. Arbitrary rotation, data fusion, thresholding, slicing, and the various illumination models are demonstrated using infrared satellite data and radar data. The results are illustrated via multiple photographs of octrees.

ABSTRACT

MICROWAVE REMOTE SENSING OF CLOUD LIQUID WATER AND SURFACE EMITTANCE OVER LAND REGIONS

Andrew S. Jones
Atmospheric Science Department

Microwave remote sensing of cloud liquid water has largely been limited to areas over ocean surfaces. This study uses data from a new microwave instrument, the SSM/I on a polar-orbiting DMSP satellite, and infrared and visible data from the VISSR instrument on the GOES satellite in geostationary orbit. The region selected for the study was an area of 500 km x 500 km centered on northeast Colorado during the first week of August 1987. The SSM/I instrument has new high frequency channels (85.5 GHz) which are more strongly attenuated by cloud liquid water than channels on previous instruments. This allows for the estimation of integrated cloud liquid water based on the microwave brightness temperature depression caused by attenuation and emission of microwave radiation at the colder cloud levels. Atmospheric attenuation due to oxygen and water vapor is determined using a millimeter-wave propagation model (MPM). The Rayleigh approximation is used for the calculation of cloud liquid water attenuation.

Surface emittance measurements at the SSM/I frequencies were made with the aid of co-located GOES infrared data during clear sky conditions. Images produced of the retrieved surface emittances suggest a strong influence by wet surfaces caused by precipitation and irrigation. Error analysis results indicate absolute errors of ±0.012 for surface emittance retrievals for the 85.5 GHz channels.

Integrated cloud liquid water retrievals show good qualitative agreement with other available data sources. Numerical error sensitivity analysis and comparison of integrated cloud liquid water retrievals for the vertical and horizontal polarizations show error estimates of 0.15 $kg \cdot m^{-2}$ including instrument noise. A bias between the horizontal and vertical polarizations of the 85.5 GHz channels was noticed in the retrieved integrated cloud liquid water amounts. The bias appears to be due to a relative instrument error between channels of approximately 1.5 K. Absolute error estimates of the integrated cloud liquid water retrievals are unavailable but calibration of the method should be possible if quantitative integrated cloud liquid water amounts are known.

ABSTRACT

FREQUENCY CHIRP OF A HYBRID DOPPLER LIDAR

Robert F. McCoy Jr.
Physics Department

A hybrid Doppler lidar utilizes a pulsed infrared carbon dioxide laser as the transmitter in a laser radar system for measuring wind velocity and direction. Some of the laser light is backscattered by aerosols that are carried by the wind. The scattered light is shifted by an amount proportional to the aerosols' radial velocity. If the frequency of the transmitting laser changes throughout a pulse, the velocity estimate of the wind field is affected.

The primary laser within the system is the hybrid cavity composed of two sections. The first section is a continuous-wave (cw) laser, and the second is a transverse excited atmospheric pressure (TEA) laser which is basically a high-power pulsed amplifier. In the past, CO_2 Doppler lidars used custom-built TEA sections costing between one-quarter and one-half million dollars. The lidar being built for the Center for Geosciences at Colorado State University utilizes commercial off-the-shelf components which result in an order-of-magnitude reduction in the cost of the TEA section. The commercial TEA sections do not appear to introduce more problems than a custom-built TEA; their problems and solutions are addressed in the thesis.

The TEA section is a gas laser and exhibits frequency chirping during a pulse. When the density of the gas within the TEA section changes, the frequency of the hybrid cavity radiation can also change. To minimize the uncertainty in the velocity estimate, the frequency chirp should be reduced to a minimal value and the resulting chirp must be known. Three different techniques to characterize the chirp are presented, along with methods to reduce the chirp. The chirp is measured directly and parameters that affect the chirp are identified. Two of the experiments yield the chirp toward the end of the pulse where the direct measurement techniques tend to provide poor data. They also provide information on the optical quality of the cavity before, during, and after the pulse. Suggestions for modifying parameters to optimize the hybrid cavity design, thus reducing the chirp, include increased cavity length, larger mode volumes, vibrational isolation of TEA laser and shorter pulse lengths.

ABSTRACT

AN EVALUATION OF THE FACTORS AFFECTING WINTERTIME QUANTITATIVE PRECIPITATION FORECASTS IN AN EXPLICIT CLOUD MODEL OVER MOUNTAINOUS TERRAIN

Michael P. Meyers
Atmospheric Science Department

A prolonged orographic precipitation event, in a relatively steady-state synoptic environment occurred over the Sierra Nevada Range in central California on 12-13 February 1986. This well documented case was investigated via the non-hydrostatic version of the CSU Regional Atmospheric Modeling System (RAMS). Two-dimensional, cross barrier simulations have shown the feasibility of producing a quantitative precipitation forecast (QPF) with an explicit cloud model. The simulated flow fields, microphysical structure, and precipitation distribution compared quite well with observations. The experiment, however, exhibited a profound sensitivity to the input sounding. Initializing with a sounding which is representative of the upstream environment is most critical to the success of the simulation.

The flow fields showed little sensitivity to the model microphysics. Sensitivity to microphysical parameters have shown that the removal of a precipitation process, such as graupel or secondary ice production due to riming, is compensated by the enhancement of other processes such as rain and aggregation. The sensitivity of lowering the graupel density effectively changed the graupel species to a graupel-aggregate hybrid which dominated the ice-phase precipitation budget, resulting in a broadening of the precipitation distribution on the lower half of the barrier.

The flow fields were sensitive to the absence of the Coriolis term, with the u-component winds weaker at the base of the barrier. The precipitation distribution was slightly affected with Coriolis turned off, with a more pronounced mid-mountain peak than in the control run, which resulted from enhanced vertical velocities over the barrier. The Coastal Range produced a seeder-type cloud but enhancement of precipitation was not evident. Sensitivity to the diabatic influences of melting were seen in the microphysical fields but showed little influence on the flow fields and resultant precipitation distribution. A standing 15 km wave was evident upstream of the barrier crest and its origin was not sensitive to latent heat effects or the Coastal Range.

ABSTRACT

THE EFFECTS OF SPATIAL VARIABILITY OF OVERLAND FLOW PARAMETERS ON RUNOFF HYDROGRAPHS

Glenn E. Moglen
Civil Engineering Department

The behavior of the overland flow system depends largely on the degree of equilibrium exhibited by the system. Large variations in discharge result from partial equilibrium conditions, while systems in complete equilibrium produce only small variations in discharge. The use of spatially averaged values to quantify hydrologic parameters for overland flow modeling is, therefore, insufficient information to accurately simulate discharge hydrographs when the system being modeled has not reached equilibrium. In contrast, a system at equilibrium exhibits a peak discharge independent of the spatial distribution of the watershed characteristics.

Uncorrelated spatial variability in each of the input parameters causes differing relative variability in overland flow discharge. Overland flow discharge is most sensitive to spatial variations in excess rainfall intensity. Manning's "n" and width produce comparable variability in discharge. Variations in slope have the smallest effect on overland flow discharge. These results are relatively independent of the spatial distribution functions used for the perturbations.

The procedures developed to analyze effects of uncorrelated spatially varied parameters are applied using spatially correlated slope input data. This is done using the spectral distribution of terrain height values for a mountainous region near Steamboat Springs, Colorado. These spectra are used to vary the slope parameter in the Manning equation. The results corroborate the earlier findings regarding the demonstrated variability of overland flow discharge at various degrees of equilibrium. The results also indicate that spatial correlation of a parameter has an influence on the magnitude and timing of the discharge variations.

The results provide a means of determining an appropriate grid spacing for sufficiently describing variability within a watershed. For durations of rainfall greater than equilibrium, the effects of spatial variability of overland flow parameters are small. Rearrangement of the equation for the time to equilibrium yields an expression for the desired grid spacing. This grid spacing provides a means of ensuring that complete equilibrium will be achieved within all grid areas, therefore minimizing the error due to partial equilibrium variations.

ABSTRACT

TWO-DIMENSIONAL RUNOFF MODELING WITH WEATHER RADAR DATA

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The objective of this study is to examine the effect of precipitation data spatial and temporal resolution on the surface runoff calculated by one-dimensional and two-dimensional, physically based, distributed parameter runoff models.

The model sensitivity to rainfall data temporal resolution is examined on both one-dimensional and two-dimensional impervious surfaces. Studies are performed using a Monte Carlo approach, where fifty simulations are performed for each value of temporal sampling resolution and rainfall duration. Results indicate that the sensitivity of both one-dimensional and two-dimensional runoff geometries increases with increasing temporal sampling resolution and with increasing rainfall duration. The sensitivity reaches an asymptote as the rainfall duration exceeds the time to equilibrium, defined by the average rainfall intensity. The asymptotic value of relative sensitivity increases with the square root of the temporal sampling interval.

The sensitivity of the two-dimensional runoff model to the spatial variability of precipitation intensity is explored. Both stochastically generated and polarimetric weather radar estimated static rainfall fields are input to the runoff model for differing rainfall durations and spatial resolutions. The sensitivity of the runoff model to rainfall intensity spatial variability is observed to decrease with increasing rainfall duration for all spatial resolutions tested. The effect of precipitation data resolution is observed by comparison with results from the finest resolution input data. The statistical deviations in model performance due to resolution coarsening are presented.

The effect of storm motion on the outflow calculated by the two-dimensional runoff model is observed using rectangular, constant intensity precipitation fields. The precipitation fields are moved in 16 directions over the watershed, at ten speeds per direction. A dimensionless storm speed and storm direction is identified which produces the largest effect on the magnitude of the outflow hydrograph peak. This dimensionless storm velocity is on the order of the runoff length divided by the time to equilibrium for an equivalent stationary storm.

Real-time polarimetric weather radar estimated rainfall fields are input to the two-dimensional runoff model in simulations with and without infiltration on one 32 km^2 and one 121 km^2 watershed to determine the effect of input data spatial resolution on model performance. In simulations without infiltration, the smaller watershed is more sensitive to input data resolution because of increased variability in rainfall volume. Statistical deviations from finest resolution results are presented. In simulations with infiltration, the interaction between the scale of the input rainfall data and infiltration processes in considerable. As input rainfall data resolution is coarsened, excess rainfall amounts decrease substantially, indicating that two-dimensional, distributed parameter, physically based runoff models must be calibrated for one input data resolution. If the resolution of the precipitation data is changed, the model must be re-calibrated.

ABSTRACT

INFERENCE OF HORIZONTAL TEMPERATURE GRADIENTS USING PASSIVE RADIOMETRIC METHODS

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There exist many situations in nature where relatively strong horizontal temperature gradients are present in the boundary layer. The purpose of this work is to investigate the impact of horizontal temperature gradients on the infrared radiance properties of the boundary layer and devise a scheme for inferring the gradient magnitude from these radiance properties.

The temperature and spectral dependence of the radiance of various atmospheric constituents are examined and the IR portion of the spectrum $500cm^{-1} \leq \nu \leq 800cm^{-1}$ is shown to be most sensitive to temperature induced radiance changes. The two important radiating gases at these wavenumbers are CO_2 and H_2O. The spectral radiative properties of these constituents are discussed. The variability of the water vapor mixing ratio is shown to be an important factor in this remote sensing application. A model is discussed which numerically estimates the radiance of the boundary layer in the presence of a horizontal temperature gradient. The results of this model demonstrate the possibility of estimating the gradient magnitude from narrow band azimuthally scanned radiance measurements.

Two parameters, the attenuation length and the centered normalized radiance, are introduced and their relationship to the gradient magnitude is explored. Using these parameters, a method is developed which permits the inference of temperature gradient magnitude from infrared radiance measurements and local pressure, temperature and mixing ratio values. The success of this technique is demonstrated by the accurate recovery of gradient magnitudes from calculated radiance data. Finally, consideration is given to sources of error and uncertainty in the measurement process and the impact of these on the inference of the gradient magnitude.

ABSTRACT

THE EFFECT OF MOVING RAINSTORMS ON OVERLAND FLOW USING ONE-DIMENSIONAL FINITE ELEMENTS

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Civil Engineering Department

Rainfall events are rarely stationary. That is to say that over any watershed, storms are spatially and temporally variable. Unfortunately, most rainfall-runoff models usually consider precipitation to be stationary and uniform. However, evidence in the literature indicates that the movement of storms can have a significant influence on runoff hydrographs. Therefore, a need for numerical models which can accommodate the movement of precipitation is recognized. This dissertation provides a better understanding of the influence of block moving precipitation on surface runoff hydrographs. Two one-dimensional finite element models were developed and used for these investigations.

Analytical expressions for each partial derivative of the momentum equation are developed for stationary storms. For moving rain storms, the behavior of the terms of the momentum equation is shown to be very complex. However, based on the analysis of the momentum equation for stationary and block moving storms, it is found that only the full-dynamic and kinematic forms of the momentum equation are suitable for simulation of overland flow. The kinematic approximation is suitable for overland flow simulation for most cases of stationary and moving storms. The time to peak of moving storms was shown to depend on the traverse time of storms and can be several times greater than the time to equilibrium for stationary storms. For partial-equilibrium hydrographs, the maximum peak discharge of equivalent block moving storms, was shown to occur when the dimensionless storm velocity was equal to 0.3 for laminar flow and 0.5 for turbulent flow using Manning's equation. The maximum peak discharge occurs when the flood wave and the storm front arrive at the downstream end of the plane at the same time. Using the results of these studies, and the finite element model, successful simulation of block moving storms over a laboratory watershed was conducted. These simulations indicate that the one-dimensional finite element model can be used to simulate runoff from moving storms over a system of planes and channels.

ABSTRACT

THE BROADBAND RADIATIVE PROPERTIES OF CIRRUS CLOUDS DEDUCED FROM AIRCRAFT MEASUREMENTS DURING FIRE

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The bulk radiative and microphysical properties of five cirrus clouds sampled via the NCAR Sabreliner on four days during the FIRE first cirrus IFO are described. These cirrus systems, which developed under a variety of synoptic weather conditions, occurred at various altitudes and ranged in geometric thickness from about 2.0 to 4.5 *km*. A broadband, infrared radiative transfer model is employed to deduce the impact of the cirrus layers on infrared radiation. This model isolates the effect of the atmospheric gases from that of the cloud ice water permitting retrieval of the cloud emittance (ϵ_{cld}) and profiles of the mass absorption coefficient (K).

For the five cirrus cloud cases, the total cloud emittance, ϵ_{cld}, ranged from about 0.4 to 0.8 and the deduced emittance profiles appear as similar functions of ice water path (IWP). Furthermore, the mass absorption coefficient, K, is found to decrease with increasing particle size ranging from about 0.48 m^2g^{-1} in the top of one layer to about 0.007 m^2g^{-1} near the base of another. This relationship is somewhat dissimilar from one cirrus system to the next suggesting the significant effect of some unmeasured microphysical property. Small particles, which have been shown by other authors to be prevalent in cirrus clouds via the spectral characteristics remotely sensed in the 8-12 μm window region, are a likely suspect. Broadband, infrared absorption coefficients (σ) are also computed and found to exhibit a similar temperature dependence as data recently presented by other authors.

The horizontal variabilities in the shortwave and infrared properties of these cirrus systems are explored. The range of variation in the shortwave properties are found to be similar to the observed range in the infrared. Good correlation was found between the shortwave albedo (ρ) and upward effective emittance ($\epsilon^* \uparrow$). A scatter plot of these two parameters agreed well with theoretical calculations assuming an asymmetry parameter of 0.7. Downward effective emittances ($\epsilon^* \downarrow$) were found to range from about 0.4 to 0.8, while the shortwave effective extinction (ζ) ranged from 0 to 0.45. $\epsilon^* \downarrow$ and ζ were not well correlated owing to cloud heterogeneities.

Finally, the current state of cirrus radiation parameterizations was briefly assessed in relation to this data set and there appears to be sufficient observational evidence to support the initial development of parameterization schemes for general circulation and climate models.

ABSTRACT

MECHANICS OF HEADCUT MIGRATION IN RILLS

Otto R. Stein
Civil Engineering Department

The proposed conceptual model relates two-dimensional headcut migration to sediment detachment just upstream and just downstream from a headcut. If upstream erosion dominates, the headcut tends to obliterate itself as it migrates upstream, eventually becoming indistinguishable from the eroding channel's bed slope. If downstream erosion dominates, the headcut face erodes from below and a definable headcut with a near vertical face migrates upstream with time.

A criterion to determine which migration mode occurs is formulated using both dimensional analysis and by equating hydraulic and sediment detachment equations. Dimensional analysis results in a time scale ratio of upstream to downstream erosion related to the upstream and downstream sediment detachment, bed slope, Reynolds number and the drop number, which represents the dimensionless headcut drop height. A physically based analysis of hydraulics and sediment detachment yields a relationship between the dimensionless terms. The resulting equation for headcut stability is favorably compared with a total of eleven laboratory measurements of headcut migration on cohesive soil.

The maximum scour depth and the total volume of eroded material produced by the impinging jet just downstream from a headcut are analyzed. A previously developed method for the prediction of the ultimate, or equilibrium, scour depth in non-cohesive bed material is modified to include scour from cohesive bed material. This method equates the sediment detachment potential of the bed material to the diffusion of a jet.

The same approach is used to determine the time rate of the maximum scour depth. Dimensional analysis relates the ratio, maximum scour depth at any time over the predicted ultimate scour depth, to the jet Reynolds number, Froude number and a dimensionless time scaled to jet properties. The change in scour depth is analytically shown to proceed at two distinct rates. For some period of time from the initiation of scour, scour rate is independent of time because the bed is within the jet potential core and diffusion has not reduced the maximum jet velocity. Beyond this time period jet diffusion decreases the rate of scour and this rate decreases with increasing time and scour depth. In the limit the predicted ultimate scour depth is approached. The dimensional and physically based analyses for scour depth compare favorably with experimental data. This data includes measurements of the ultimate scour depth and the change in scour depth with time for ten runs on cohesive soil, eight runs on sand d_{50} = 1.5mm and six runs on sand d_{50} = 0.15mm.

ABSTRACT

MICROWAVE REMOTE SENSING OF A PRECIPITATING ATMOSPHERE

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Throughout the 10-100 GHz spectrum, the scattering and absorption properties of atmospheric hydrometeors and gases vary widely. As a result, multifrequency techniques for passive microwave estimation of precipitation have been proposed. The emission-based, lower frequency observations (< 37 GHz) effectively respond at lower altitudes, while the scattering-based higher frequencies (≥ 37 GHz) respond at higher altitudes, thus providing a potential means to link self-consistent precipitation estimates to the multifrequency brightness temperatures T_B. Unlike many schemes which link T_B to the liquid water content, this study emphasizes the use of scattering-based channels to infer information on the ice water content. The high altitude ice region remains fairly unobscured to a spaceborne sensor, suggesting the implementation of the scattering-based channels in a top-down methodology as the first step in a retrieval of the cloud vertical structure.

Extensive model simulations of the upwelling T_B were performed throughout clouds whose bulk microphysical properties were deduced from multiparameter radar data and cloud model output obtained during the 1986 Cooperative Huntsville Meteorological Experiment (COHMEX). A highly accurate plane-parallel microwave radiative transfer model with Mie phase matrices was used to solve the equation of transfer in a scattering atmosphere with a land surface. COHMEX aircraft radiometer measurements at 18, 37, and 92 GHz were compared with the output of the multiparameter radar-initialized radiative transfer model. Deviations at 92 GHz were attributed to uncertainties in the bulk density and size distribution of the ice region. Using both multiparameter radar observations and cloud model output, the 37-85 GHz T_B difference (ΔT_B) was found to be sensitive to the amount of integrated ice water path (IWP) lying above the rain, independent of ice density. Presence of coexisting cloud water and ice had the net effect of compressing the ΔT_B for a given IWP. Over convective regions, 85 GHz T_B depressions < 200 K were noted to be relatively insensitive to the amount of underlying liquid water content, and mainly dependent upon the optical thickness of the ice layer.

ABSTRACT

SOCIAL LOAFING AND VIGILANCE DECREMENT WHILE MONITORING DIFFERENT LEVELS OF SIMULATED AIR TRAFFIC

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Using a computerized simulation of an air traffic control display, this study examined the phenomenon of social loafing (a decrease of individual contribution in a group setting) and vigilance decrement (the decrease in monitoring performance over time). A total of 96 introductory psychology students served as subjects in a 2 X 2 X 2 X 3 split-plot design. The independent variables were the difficulty of the task (easy, hard), perceived uniqueness of an individual's contribution (unique, non-unique), and identifiability of individual performance (identifiable, non-identifiable). Additionally, three 10-minute time blocks within the simulation were examined. Groups of four subjects were instructed on, and then participated in, a 30-minute simulation of an air traffic controller radar screen. Subjects were asked to monitor the simulated traffic for a critical stimulus of '999' in the display. Subject performance was recorded as the latency of response to a critical stimulus once presented. Results showed significant main effects for task difficulty and for time block within the simulation. Additional results showed the failure of the identifiability and uniqueness manipulations hypothesized as necessary for social loafing to occur. Both failures may be related to the lack of perception of a group setting by the subjects. It is recommended that future studies increase subject perception of group membership.

ABSTRACT

THE INFLUENCE OF TOPOGRAPHY ON COLORADO FRONT RANGE SNOWSTORMS

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Atmospheric Science Department

This study utilizes both an extensive set of observations and mesoscale model simulations to isolate and describe the important influences of complex terrain on Colorado Front Range winter storms, with an emphasis on snowfall distributions. Specifically, the interaction of various types of cold, low-level air masses with topography and the larger-scale flow is described. Frequently, the heaviest snowfall does **not** coincide with the steepest terrain gradients, as might be expected, due to this interaction. Field measurements of several snowstorms during the 1987-89 time period include special CLASS (Cross-chain Loran Atmospheric Sounding System) vertical profiles, standard National Weather Service (NWS) and National Meteorological Center (NMC) surface and rawinsonde data, surface observations collected by a trained snow-spotter network, profiler data, Doppler reflectivity and velocity scans, and Geostationary Operational Environmental Satellite (GOES) images. The numerical predictions are produced by the CSU Regional Atmospheric Modeling System (RAMS), using two- and three-dimensional non-hydrostatic simulations. The versions of the model employed in this study utilized both horizontally homogeneous initializations and initial fields made up of NMC upper-air grids and rawinsondes. Most simulations employed full microphysics. A omit comparison between model-predicted dynamic and microphysical fields and observational data is described for the 30-31 March 1988 snowstorm along the Colorado Front Range.

Of particular interest in this study is the role of trapped cold air masses over the foothills and adjacent plains during the evolution of snow-producing synoptic scale disturbances. Specifically, these include two types of precipitating easterly ("upslope") flows along the Colorado Front Range: cold-air damming situations and arctic outbreaks. By no means are the dynamical features of these two types of storms mutually exclusive. The investigation includes detailed case studies of each storm type. The cold air damming process concentrates snowfall, typically in the foothills and adjacent areas to the east. A blocked low-level stable layer causes overrunning in a north-south band over and near the foothills. A quite different scenario, the cold outbreak, requires the establishment of an arctic air mass in the low levels. In this case, overrunning occurs as moist westerly winds aloft flow over the arctic air mass, producing snowfall in the foothills and plains.

The problems with forecasting precipitation amounts during these situations are well-known. This project isolates two of the primary mechanisms which have caused many of these problems. Both of these dynamical processes must be considered by the wintertime forecaster as major contributors to heavy snowfall in this region.

3. CONCLUSION

The Geosciences Fellowship program has been very successful from the perspective of the Fellows and from the research projects that comprise the Center for Geosciences. Nineteen graduate degrees had been granted by Colorado State University (CSU) as a result of the program up to the time that this Final Report was written. It is expected that the Fellowship program will have contributed at least partially to 26 degrees by the time that Fellows who still are working on their programs of study have finished.

The Fellowship program also has been very successful in maintaining and strengthening the Geosciences research community through the employment of its graduates. The following graduates are employed by the Center for Geosciences as professional scientists:

Robert McCoy
Joseph Turk

Others are employed at federal research laboratories, including:

James Bossert - Los Alamos National Lab, Department of Energy
Raul Alvarez - Environmental Protection Agency

Private industry has employed several of the former Fellows:

Thaddeus Cline
Russell Huonder
Jerry Richardson
William Smith
Paul Weiler

Former Fellow Otto Stein has become an Assistant Professor at Montana State University. The largest group of Fellows are working on additional advanced degrees at Colorado State University and elsewhere:

Deborah Anthony - CSU
Charlotte Atwater - CSU
Keely Costigan - CSU
Andrew Jones - CSU
Michael Meyers - CSU
Glen Moglen - MIT
Peter Olsson - CSU

The Fellows contributed significantly to the research activities of the Center for Geosciences. The interdisciplinary character of research at the Center was particularly enhanced by the efforts of the Fellows. For example, Joseph Turk worked extensively with Andrew Jones on the theory and interpretation of atmospheric microwave measurements and with Fred Ogden on using radar data as input to a hydrologic model. The Fellows also were senior authors or co-authors on a number of scientific publications.